

# ADVANCED MATERIALS TECHNOLOGIES

## Supporting Information

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### Application of 3D Printing for Smart Objects with Embedded Electronic Sensors and Systems

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**Title: Application of 3D printing for smart objects with embedded electronic sensors and systems**

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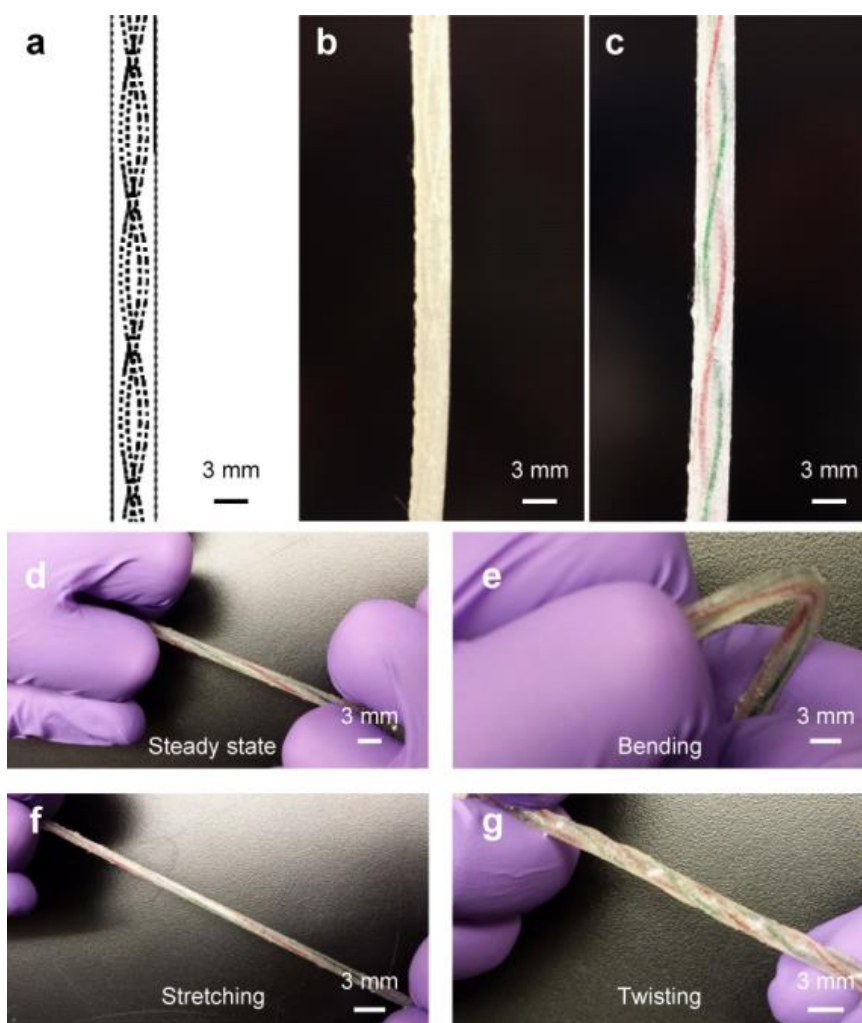
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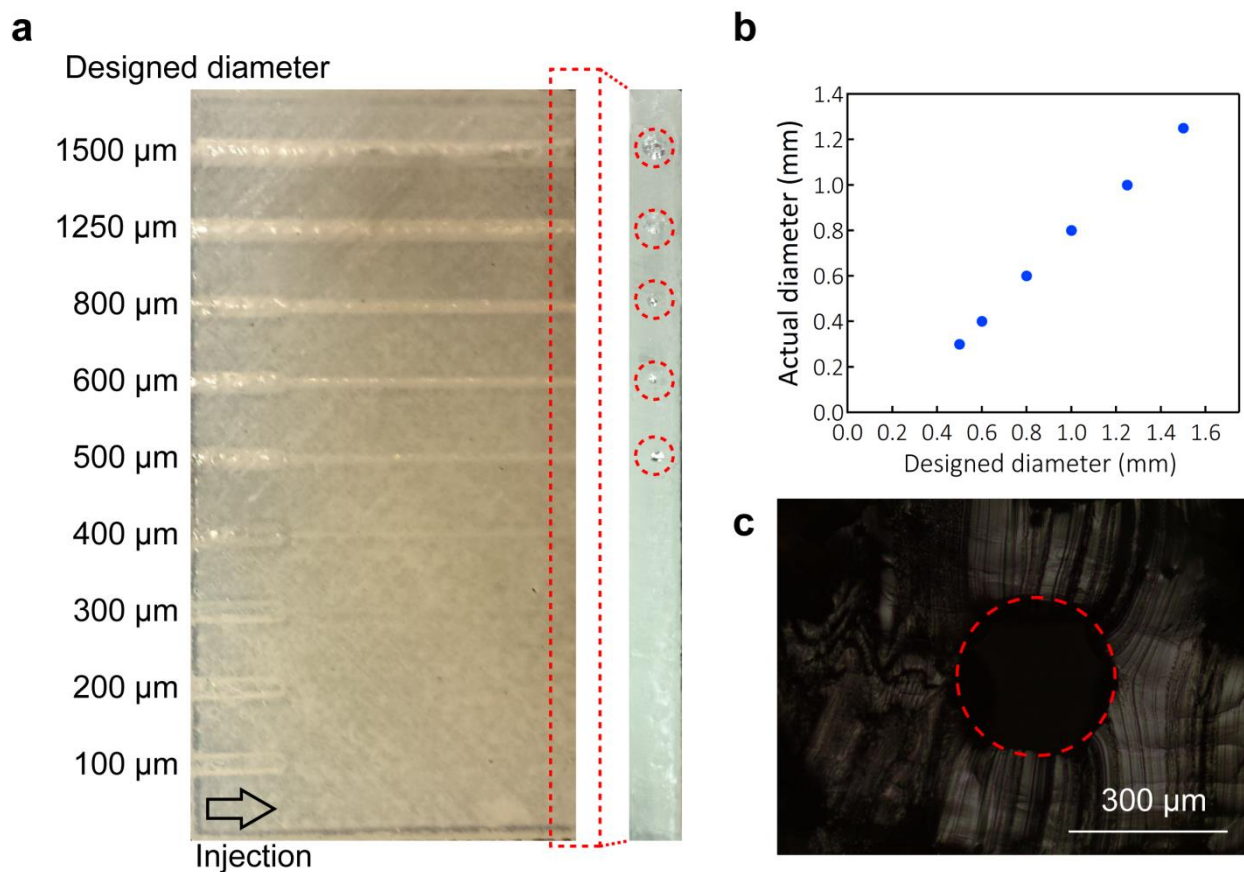
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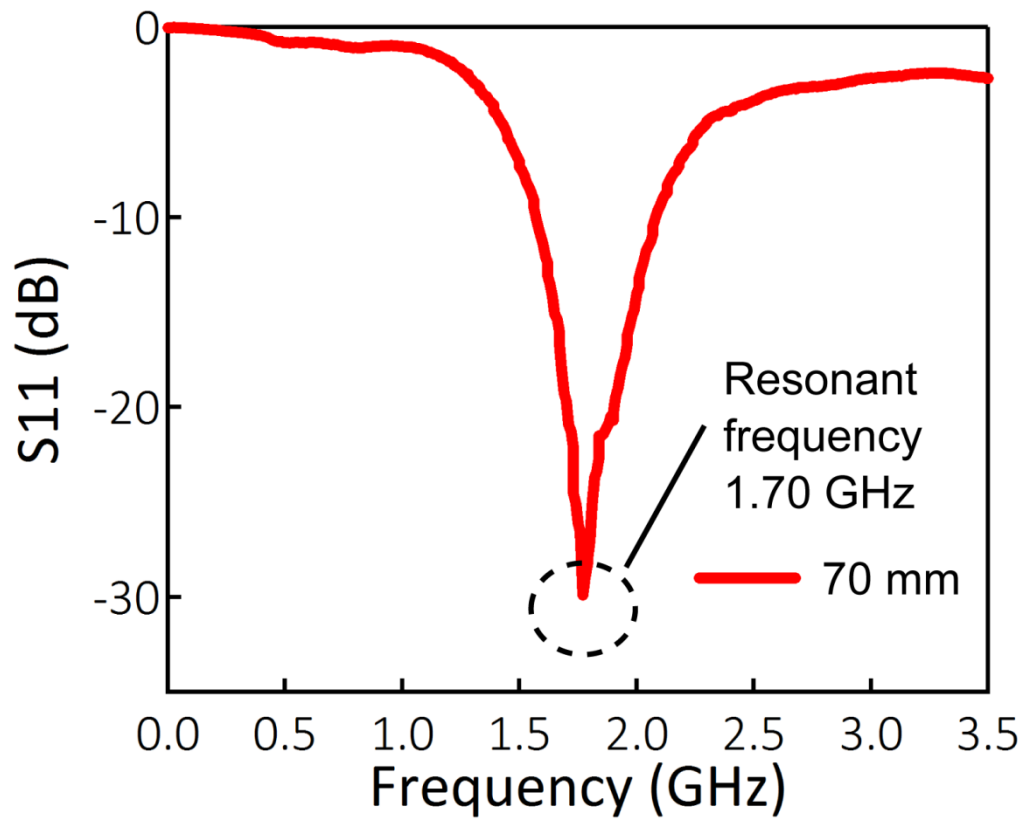
Keywords: 3D printing, liquid-state electronics, personalized smart objects, embedded systems



**Figure S1.** **a)** Design schematic of the double helix channels. **b** and **c)** 3D printed double helix channels (**b**) before injecting liquids and (**c**) after injecting liquids. **d-g)** Images of the double helix structure (**d**), at rest, (**e**), when bent, (**f**), when stretched, and (**g**), when twisted.



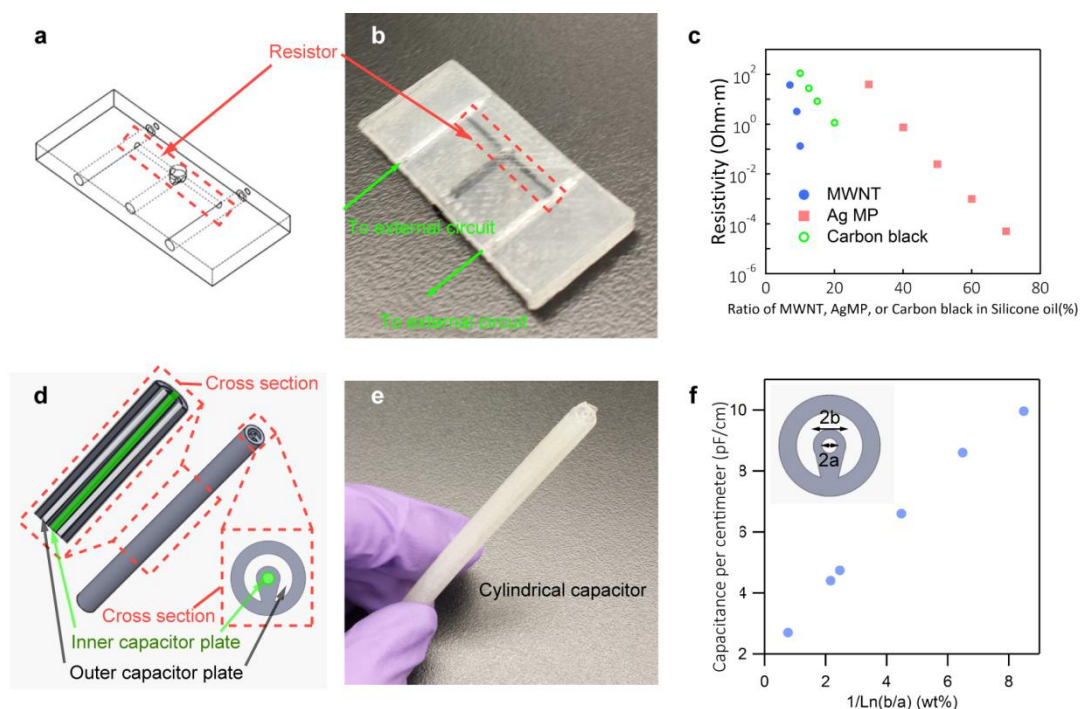
**Figure S2.** a) Optical image of 3D printed channels with different diameters. b) A graph showing the relationship between the designed diameter and the actual 3D printed diameter of the channels. c) Cross sectional image of the channel with a 300  $\mu\text{m}$  diameter (500  $\mu\text{m}$  design).



**Figure S3.** Resonant frequency of the 3D printed antenna with 70 mm dipole length.

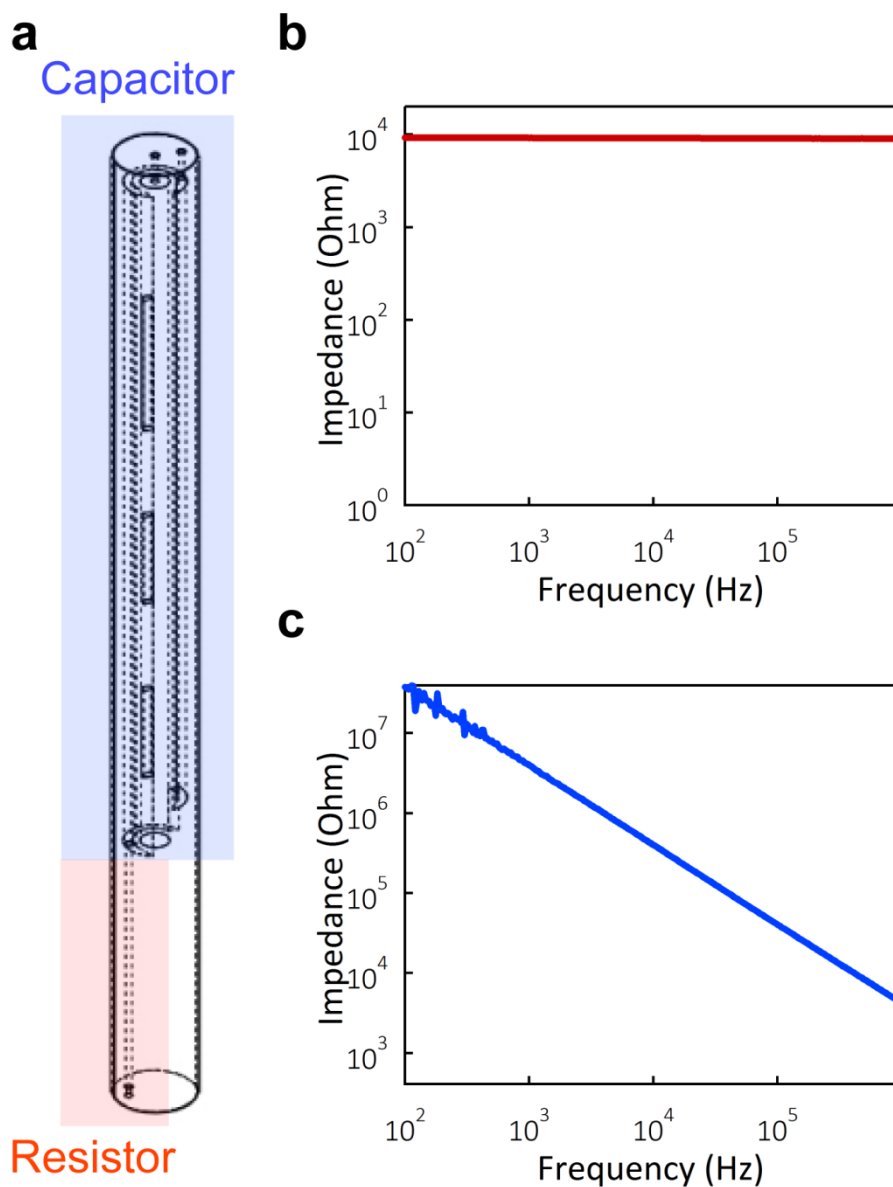


**Figure S4.** Wireless transmission of video content from a camera to a laptop using 24.5 mm dipole antennas installed into a video receiver and transmitter. Left side images in boxes are top views of the transmitter and receiver with liquid dipole antennas.

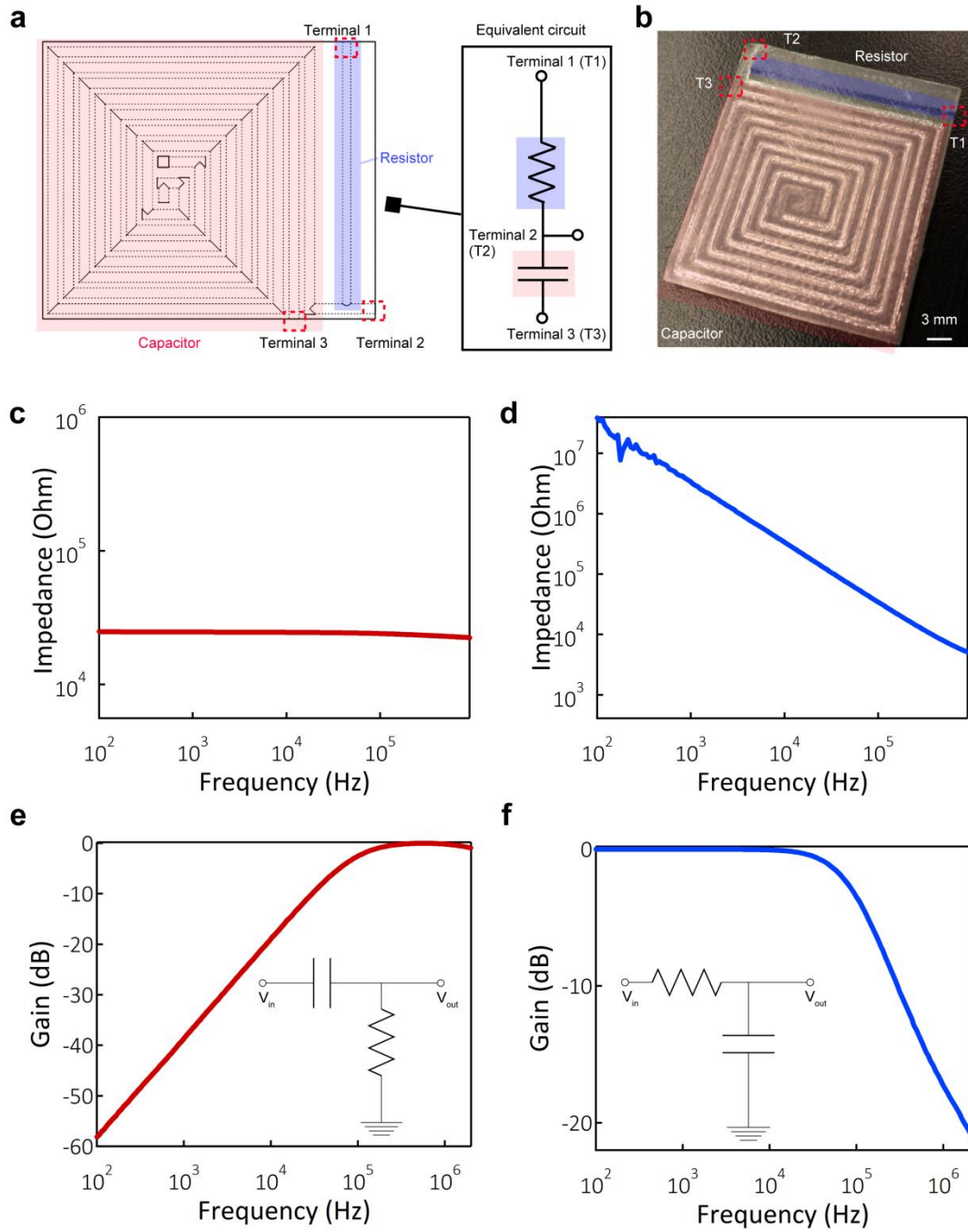


**Figure S5.** **a)** Schematic image of the design of the liquid-state resistor. **b)** Optical image of the 3D printed liquid-state resistor. **c)** The resistivity of the various conductive liquids with respect to the ratio of multiwall carbon nanotubes (MWNT), silver microparticles (AgMP), or carbon black. **d)** Schematic of the cylindrical capacitor. **e)** Optical image of a 3D printed cylindrical capacitor. **f)** The capacitance per length of the cylindrical capacitor with respect to  $1/\ln(b/a)$ .

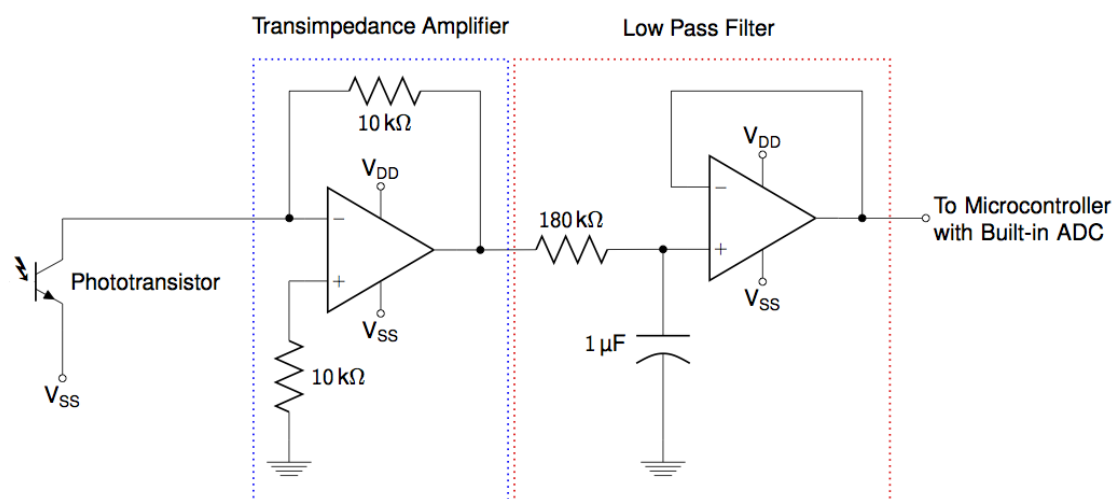




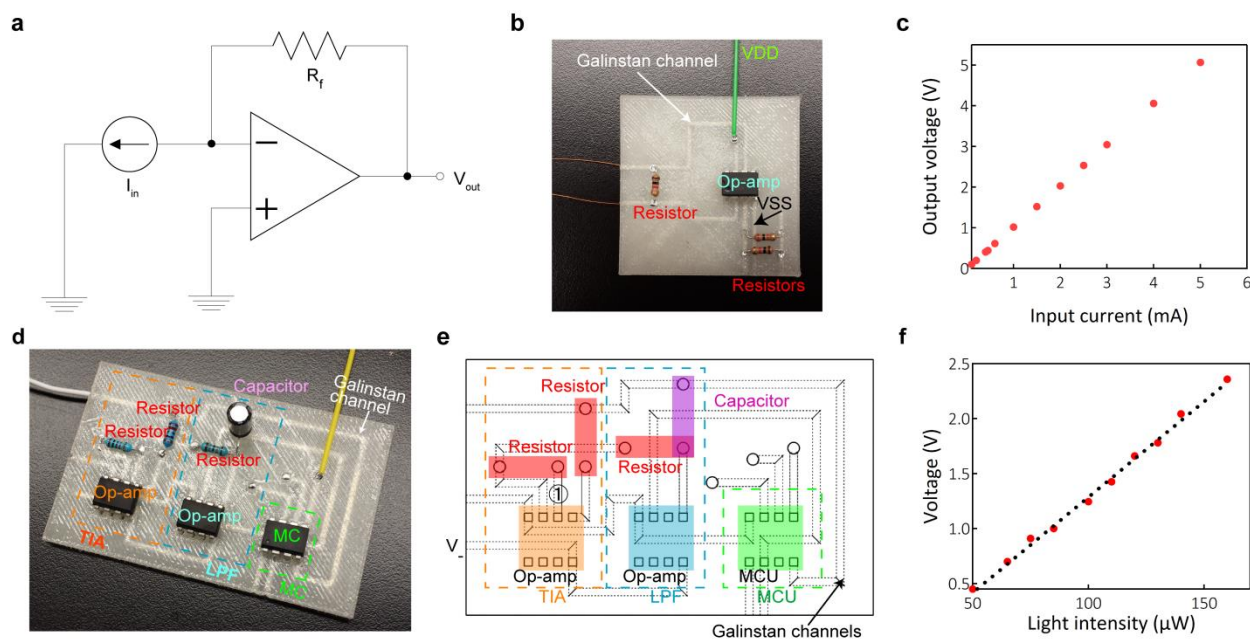
**Figure S6.** **a)** Schematic of the cylindrical filter. **b)** Impedance of the capacitive segment with respect to the operating frequency. **c)** Impedance of the resistive segment with respect to the operating frequency.



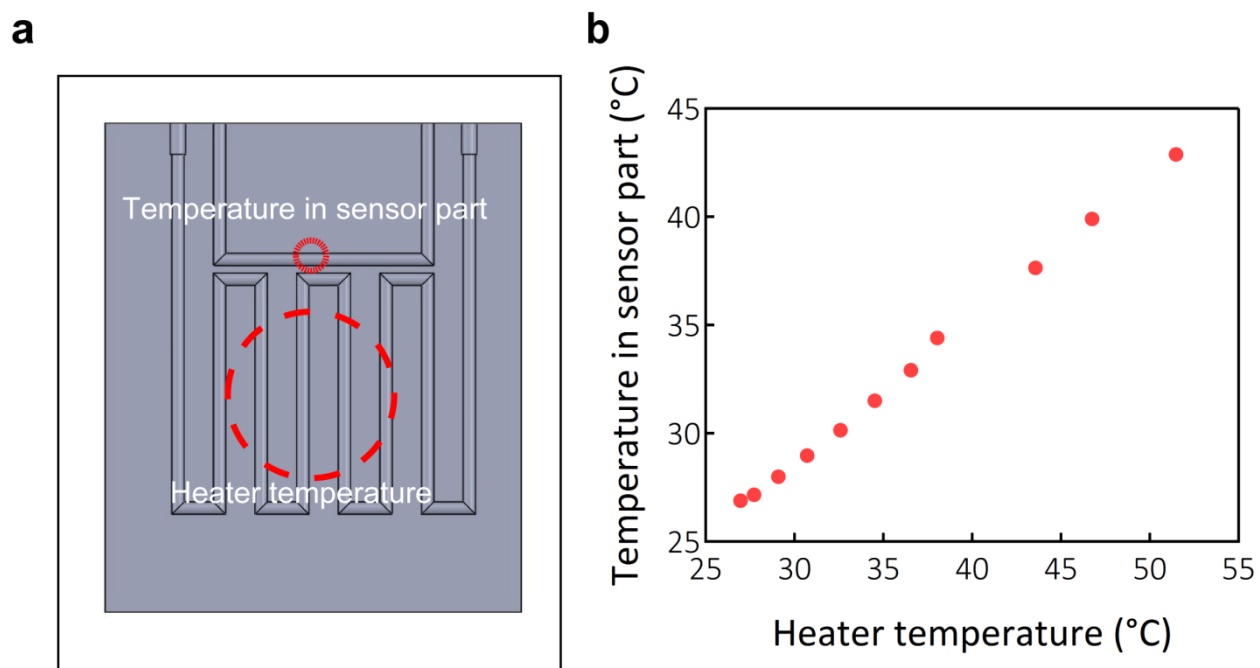
**Figure S7.** **a)** Schematic of the 2D filter. **b)** An optical image of the 3D printed liquid state resistor. **c)** Impedance of the resistive segment with respect to the operating frequency. **d)** Impedance of the capacitive segment with respect to the operating frequency. **e)** Frequency response of the high pass filter using the series 3D printed resistor and capacitor. **f)** Frequency response of the low pass filter using the series 3D printed resistor and capacitor.



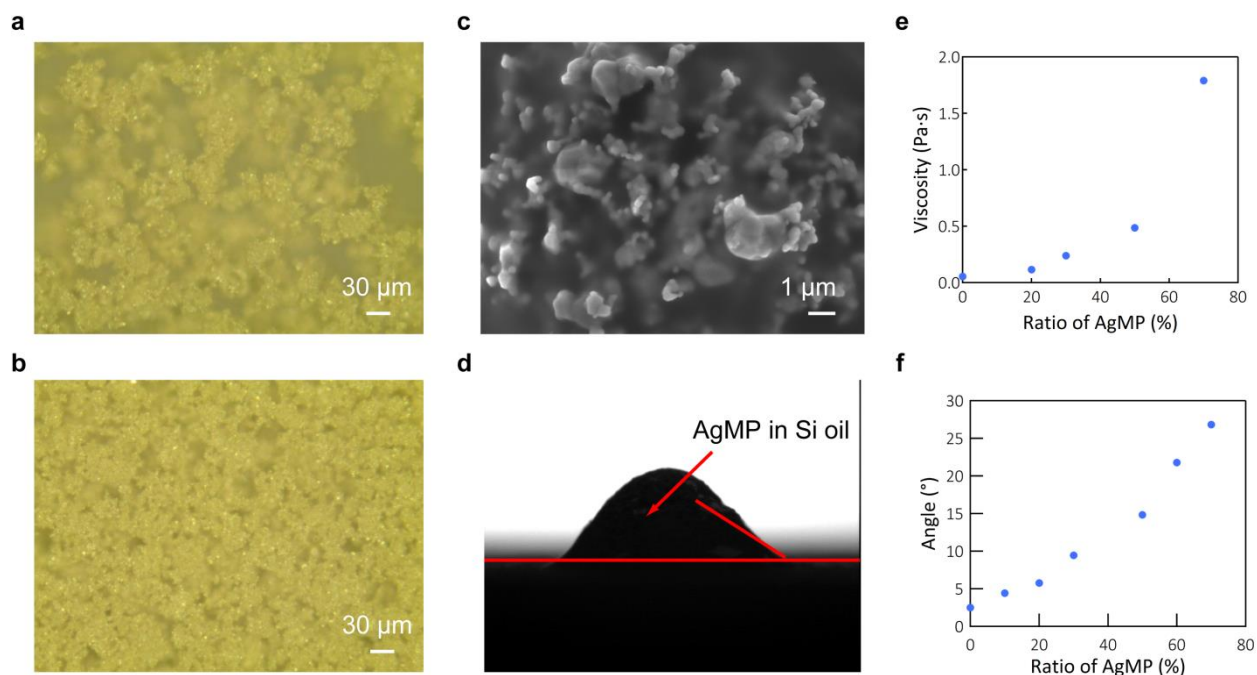
**Figure S8.** Schematic of the photo-detection circuit indicating that the transduced current signal is converted to voltage and is filtered as it passes through the TIA and LPF stages respectively.



**Figure S9.** a-c) Transimpedance amplifier circuit. a) Electrical schematic of the transimpedance amplifier (TIA) circuit. b) Optical image of the 3D printed TIA circuit. c) Graph of the output voltage with respect to the input current. d-f) TIA-LPF-MC 2D circuit. d) 3-D printed TIA-LPF-MC 2D circuit. e) Drawing of the TIA-LPF-MC circuit. f) Output voltage with respect to the input light intensity.



**Figure S10.** **a)** Schematic of the electronic heater and temperature sensor. **b)** Relationship between temperature at the heater and at the sensor.



**Figure S11.** **a** and **b**) Optical images of **(a)** 30% silver micro particles(AgMp) and **(b)** 70% AgMp in silicone oil. **c**) Scanning electron microscope (SEM) image of the 70% AgMP solution. **d**) Contact angle of the 70 % AgMP solution on Filaflex. **e**) Viscosity with respect to the ratio of AgMP. **f**) Contact angle with respect to the ratio of AgMP in the silicon oil.